Growth temperature dependence of InAs islands grown on GaAs (001) substrates

° Osamu Suekane, Toshiko Okui, Masahiro Takada, Shigehiko Hasegawa and Hisao Nakashima
The Institute of Scientific and Industrial Research, Osaka University,
8–1 Mihogaoka, Ibaraki, Osaka 567–0047, Japan

Scanning tunneling microscopy (STM) connected to molecular beam epitaxy (MBE) has been used to investigate InAs islands and wetting layers (WLs) on GaAs (001) substrates. It has been found that InAs islands initially nucleate at monatomic steps on WLs. Observation of islands formation and step structures on WLs is very important for controlling size, density and spatial arrangement of islands. In this study, we have investigated growth temperature dependence of InAs quantum dots grown on GaAs (001) substrates using STM and photoluminescence (PL).

All samples were fabricated by MBE. A 200nm GaAs buffer layer was first grown at 580 ℃. After the substrate was cooled to a temperature for InAs growth, 1.6 monolayers (MLs) InAs was deposited. The formation of InAs islands was confirmed by the appearance of facet-related streaks in reflection high-energy electron diffraction (RHEED) patterns. The coverage of InAs was estimated from the result reported that the facet-related RHEED pattern appears at a coverage of 1.6 MLs [1,2], where 1 ML is defined by atom density of GaAs (001) surfaces. For STM observation, samples were immediately cooled down to room temperature after the growth of InAs, and then transferred to the STM chamber. To investigate optical characteristics, samples covered with a 50nm GaAs cap layer were also grown under the same growth condition as the samples for STM observation. A GaAs cap layer was grown at the InAs growth temperature without growth interruption to suppress the change of size of InAs islands. PL measurements were carried out at 5K using an Ar^+ laser line at 514.5nm as an excitation source.

Figures 1(a), 1(b) and 1(c) show STM images for surfaces with InAs islands and wetting layers formed at 420 ℃, 450 ℃ and 480 ℃, respectively. Scan area is 400nm×400nm. The average sizes of islands in Fig. 1(a)–1(c) are 7nm, 16nm and 20nm along [110] direction, and 14nm, 23nm and 40nm along $[1\bar{1}0]$ direction. The densities of islands estimated from the STM images are $4.6 \times 10^{11}\mathrm{cm}^{-2}$, $1.3 \times 10^{11}\mathrm{cm}^{-2}$ and $5.7 \times 10^{10}\mathrm{cm}^{-2}$, respectively. It is found that the size and density of islands strongly depend on the growth temperature of InAs. With increasing InAs growth temperature, InAs island density becomes low and the size becomes large. These results indicate that by varying InAs growth temperature, the size and density of InAs islands can be controlled.

Fig. 2 shows low-temperature (5K) PL emission spectra obtained from GaAs capped InAs quantum dot samples grown at (a)420 ℃, (b)450 ℃ and (c)480 ℃, respectively. The peaks observed from 900 to 1000nm are considered to be due to InAs quantum dots since PL spectra taken from samples with a wetting layer and no quantum dots display little emission at 900–1000nm while a sharp line around at 855nm is observed. With increasing the growth temperature of InAs quantum dots, the PL spectra display significant emission at longer wavelengths. This red shift agrees with the STM result that larger islands are grown at higher growth temperature. For the samples grown at 450 and 480 ℃, multiple peaks are observed in the PL spectra at low excitation densities, as shown in Fig. 2. Increasing the excitation density leads to both the increase in intensity of peaks at shorter wavelength and the appearance of additional lines below 900nm. In contrast, for the quantum dot sample grown at 420 ℃, PL spectrum contains a single broad peak although the peak has a tail at long–wavelength side. Moreover, increasing the excitation density leads to blue shift of the PL line.

We will discuss these PL results in terms of the variation of the size and the density of InAs quantum dots (islands), which is observed by STM.

[1] H.Schuler, et.al., Microelectronics Journal,30,(1999)341.
[2] Ch.eyn, et.al., J.Cryst.Growth,210,(2000)421.

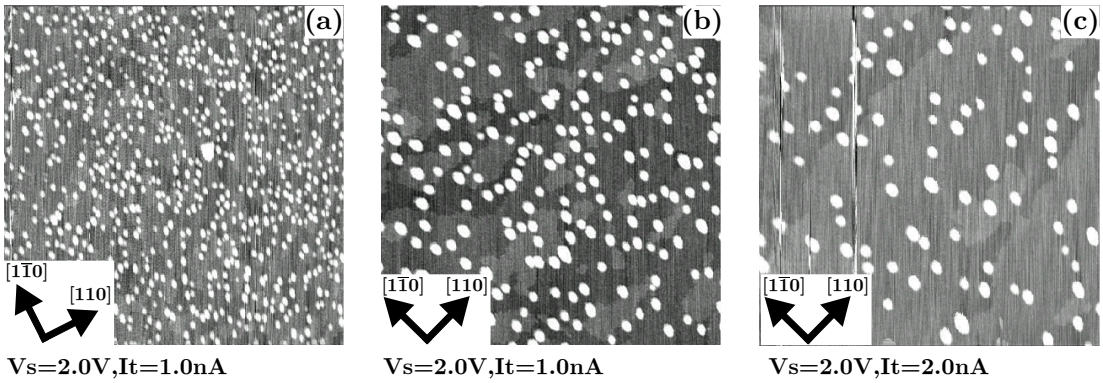

Figure 1: STM images (400 nm × 400 nm) for surfaces with 1.6MLs InAs islands and wetting layers formed at (a)420 ˚C, (b)450 ˚C and (c)480 ˚C, respectively.

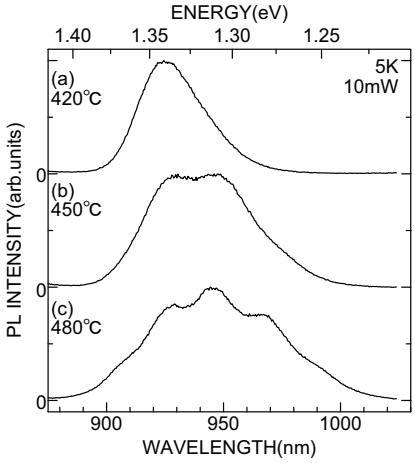

Figure 2: Low-temperature (5K) PL emission spectra obtained from GaAs capped 1.6 ML InAs quantum dot samples grown on GaAs (001) substrates at (a)420 ˚C, (b)450 ˚C and (c)480 ˚C, respectively.

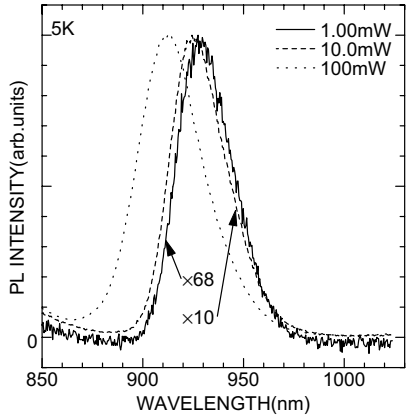

Figure 3: Excitation power dependence of PL spectra of InAs quantum dots grown at 420 ˚C.